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MAIN PAPER

Sub-Theme : Post Harvest and Food Engineering

Influence of Air Flow Rate on Drying Characteristics of Clove

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Abstract

Clove is one of the major state crops in South Sulawesi, Indonesia. In 2011 total planted area in this region reached about 44,000 hectares. Although drying is a crucial step, information concerning the drying behaviors of clove is limited. This research was designed to understand such behaviors, especially when drying air flow rates were varied under a constant drying temperature. This study was conducted from October 2012 to January 2013. Samples used were mature green-cloves, obtained from Sinjai Regency - South Sulawesi. The initial moisture content of these samples were about 70%-wb (wet basis). Three levels of drying air velocity (0.5, 1.0, and 1.5 m/s) were applied under a constant drying temperature of 45°C. About 25 g sample arranged in a single layer was used for every drying run. The experiment was carried out using a tray dryer, *Model EH-TD-300 Eunha Fluid Science.* A digital balance was used to weigh the sample at every hour elapsed drying time. The drying process was terminated when the weight reduction had reached about 0.03 g. It took about 26, 24, and 20 hours to reach such reduction for drying air velocities of 0.5, 1.0, and 1.5 m/s, respectively. Their corresponding final moisture contents were about 16, 10, and 10%-wb. This result indicated that drying air velocity really affected the clove drying rate. The second finding was, among eight thin-layer drying models tested, Hii *et al.* and Wang & Singh models appeared to be the best fitted models, R^2 greater than 0.997. Hii *et al.* performed well at 0.5 m/s drying air velocity, while Wang & Singh model was superior at higher drying air velocities, 1.0 and 1.5 m/s.

Key words: clove, drying, temperature, drying-air

Introduction

Clove is one of the strategic estate crops in South Sulawesi, Indonesia. BPS (2011) reported that total planted area of clove in this region in 2010 reached up to about 45.000 ha with total production of around 16.000 ton. Luwu, Sinjai, Bulukumba and Wajo Regencies are the top four regencies in this province in clove production. Antara News (05 July 2010 04:59 WITA) reported that during the harvest season in 2010 dry-clove price was about Rp 30.000 - Rp 35.000 per kg. This price would tell the economic value of this crop.

Although this crop has a high economic value, most of the post harvest handling process of clove was conducted traditionally, including for its drying process. In general, cloves will be sun dried soon after being harvested since its moisture content is relatively high, up to about 70% wet basis (wb). Delaying the drying process may disadvantage the clove quality.

Similar to other crops, the drying characteristic information is essentially needed to determine the best drying period of the clove, both under sun-drying and mechanical drying process. Without this information, a proper drying process that can prevent or minimize the clove's potential mechanical damage cannot be performed. Research on clove drying had been reported by many researchers. Among others, Somantri (2001) observed the effect of fermented treatment on the model and simulation behaviors of deep-bed clove drying under four different levels of temperature (45, 50, 55, and 60 °C) and relative humidity (25, 30, 40, and 50%), and Khathir *et al.* (2008) conducted a study related to the drying of clove using greenhouse effect solar dryer integrated by biomass energy. Most of the previous studies were mostly related to the effect of temperatures on the drying characteristics of cloves. For that reason, this study was particularly designed to figure out the effect of air flow rate on single layer drying characteristics of mature green clove.

Materials and Methods

Sample

About 2 kg of fresh and mature cloves were harvested from the field located at Sinjai Regency - South Sulawesi, Indonesia. Some of these cloves, however, had been over-ripe as indicated by their red color. To have a more homogeneous sample, the green and red cloves were separated during the experiment. This paper, however, will only focus on the study results of the green cloves. The initial moisture contents of the green clove samples were about 70%-wb (wet basis). The clove samples used in this study was the unfermented one.

Methods

The experiment was conducted at the Processing Laboratory of Agricultural Engineering Department of Hasanuddin University during the period of October 2012 - January 2013. A tray dryer, *Model EH-TD-300 Eunha Fluid Science,* was utilized to dry the cloves. Figure 1 shows the schematic diagram of this dryer. Drying air velocity was calibrated on the air outlet of the dryer using a portable digital anemometer (0.1 m/s accuracy). A digital balance with an accuracy of 0.001 g placed close to the dryer was utilized to measure the sample weight across drying time.

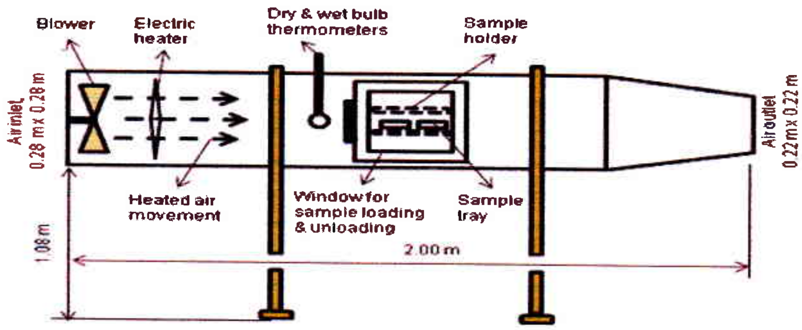

Figure 1. Schematic diagram of the tray dryer Model EH-TD-300 Eunha Fluid Science.

Three different levels of air velocity (0.5, 1.0, and 1.5 m/s) under constant drying temperature of 45°C were exercised in this research. This low drying temperature was considered to be reasonable since it was on the temperature range commonly applied by other researchers.

As mentioned before Somantri (2001) used four levels of drying temperature, namely 45, 50, 55 and 60 °C, when observing the effect of fermented treatment on model and simulation behavior of deep-bed clove drying. Khathir *et al.* (2008) also reported that the temperature of the drying chamber of the integrated dryer by biomass energy during their experiment was ranging from 36 to 46°C.

The initial weight of each sample was around 25 g. The drying temperature and air velocity were stabilized for about one hour before the sample was loaded into the drying chamber. The initial weight of each sample was recorded prior to the loading process. The weight of the sample was then recorded for every hour elapsed drying time. The sample was unloaded from the drying chamber any time the weighing process was performed. The drying process was terminated when the weight change of the sample was less than or equal to 0.03 g. It was assumed that at this point time the sample weight was in an equilibrium stage. The sample was then oven-dried to get their dry weight. The dry-basis moisture contents (Mc_{db}) of the sample across elapsed drying time were calculated for each drying air velocity.

Data Analysis

All calculated Mc_{db} were transformed into moisture ratio for elapse drying time ($MR_{(t)}$) using the following formula:

$$MR_{(t)} = \frac{Mc_{db(t)} - Me}{Mo - Me}$$

Where Mo is the initial Mc_{db} (% dry basis), $Mc_{db(t)}$ is the Mc_{db} at elapsed drying time t (% dry basis), and Me is the equilibrium moisture content (% dry basis) using the final Mc_{db} of each drying run.

The characteristics of the moisture ratio across the drying time were then fitted to the thin layer drying models depicted in Table 1. The models were used by Muhidong *et al.* (1992), Corrêa *et al.* (2006), Kingsly *et al.* (2007), Yadollahinia *et al.* (2008), Hii *et al.* (2008), Ibrahim *et al.* (2009), Meisami-asl *et al.* (2009), Muhidong (2011), and Muhidong *et al.* (2012).

Table 1. Thin-layer drying models tested in this research.

No	Model Name	Equation
1	Newton	MR = exp(-a.t)
2	Henderson and Pabis	MR = a.exp(-b.t)
3	Page	MR = exp(-a.t^b)
4	Modified Page	MR = exp(-$(a.t)^b$)
5	Two term model	MR = a.exp(-b.t) + k.exp(-d.t)
6	Verma *et al.*	MR = a.exp(-b.t) + (1-a).exp(-k.t)
7	Diffusion approach	MR = a.exp(-b.t) + (1-a).exp(-b.k.t)
8	Hii *et al.*	MR = a.exp(-b.t^k) + d.exp(-e.t^k)

Where t represents elapse drying time (in hour) and a, b, k, d, and e are drying constant.

The magnitude of each drying constant was determined using the Microsoft Excel Solver. This Solver would minimize the total quadratic-difference between the predicted and observed $MR_{(t)}$ values by automatically adjusting the values of the defined drying constants. The final adjusted values of the drying constants would then represent the true values of the drying constants of the corresponding model. Hii *et al.* (2008) also used the Microsoft Excel Solver to support their analysis. A model with the highest R^2 value and at the same time produced the smallest Chi-squared (χ^2) and the Root Mean Squared Error (*RMSE*) values was considered to be the best fitted model to represent the behavior of the mature green cloves during the single-layer drying process at the given drying temperature and air velocities. The RSQ function of the Microsoft Excel was utilized to calculate the R^2 value. As Mohammadi *et al.* (2008), the Chi-squared (χ^2) and RMSE values were determined using the following methods:

$$X^2 = \frac{\sum (MR_{(observed)} - MR_{(predicted)})^2}{N - n}$$

$$RMSE = \frac{\sqrt{\sum (MR_{(observed)} - MR_{(predicted)})^2}}{N}$$

Where N symbolizes the number of observations and n is the number of parameters involved in the model.

Results and discussion

The behavior of clove's moisture content during the experiment was depicted in Figure 2. Throughout the experiment, it was also observed, as indicated by this figure, that it required about 26, 24, and 20 hours to reach the equilibrium moisture content of the clove for drying air velocities of 0.5, 1.0, and 1.5 m/s, respectively. Their corresponding moisture contents were about 16, 10, and about 10%-wb or 20, 11, and 11%-db. This result indicated that drying air velocity really affected the clove drying rate.

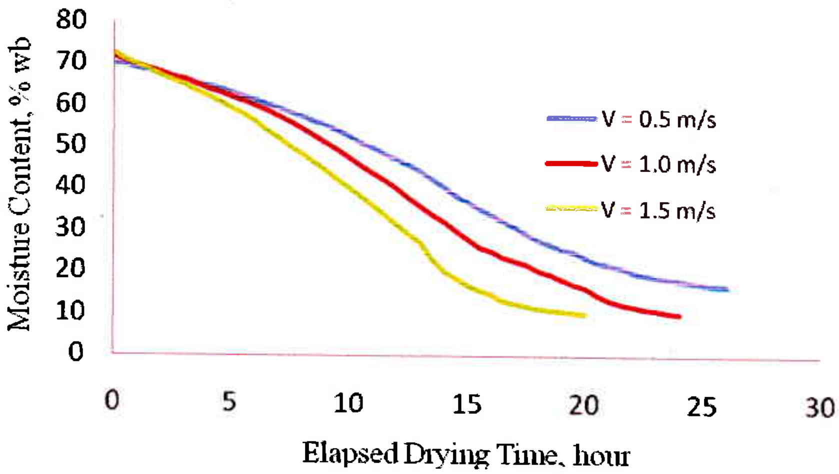

Figure 2. Clove's moisture contents across elapsed drying time.

The equilibrium moisture contents (dry basis) mentioned above were then utilized to determine the moisture ratio across elapsed drying time for each drying run, $MR_{(t)}$. Figure 2 provided information regarding the reduction pattern of the $MR_{(t)}$ across the elapsed drying time.

This figure indicated that the behavior of the $MR_{(t)}$ values across elapsed drying time followed an exponential pattern.

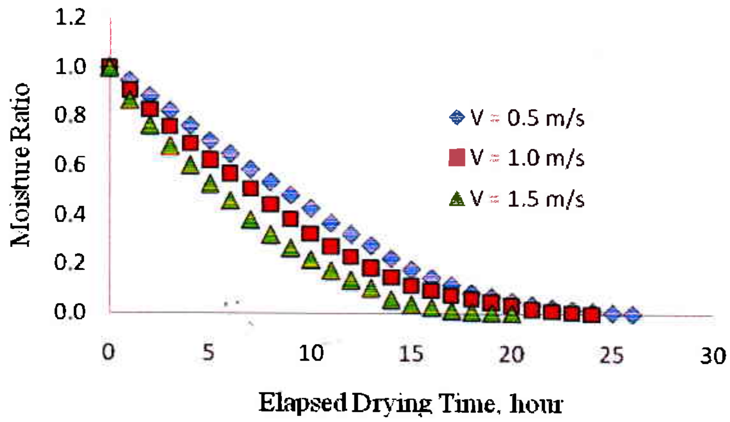

Figure 3. Trend of Moisture Ratio (MR) across elapsed drying time

The exponential pattern exhibited by the MR as shown in Figure 3 was undeniably relevant to all alternative models presented in Table 1. This figure also confirmed that the drying rates of clove would be affected by drying air velocities. Based on this phenomenon, a goodness of fit evaluation was carried out on each drying run. The results of this evaluation were shown in Table 2.

Based on the magnitudes of R^2, Chi-squared, and RMSE values, it was found that the Hii *et al.* model: $MR = 0.478794.\exp(-0.019867.t^{1.43089}) + 1.632046.\exp(-0.478794.t^{0.019867})$ was the best one to predict the behavior of the mature green clove drying rate at the drying air velocity of 0.5 m/s with R^2, Chi-squared and RMSE values were about 0.997275, 0.000381 and 0.017609, respectively. On the other hand, Wang & Singh model was apparently superior at higher drying air velocity (1.0 and 1.5 m/s). The Wang & Singh models obtained were:

At drying air velocity of 1.0 m/s, $MR = 1 - 0.08569.t + 0.001846.t^2$ (R^2, Chi-squared and RMSE values were 0.999229, 0.000082 and 0.008666, respectively)

At drying air velocity of 1.5 m/s, $MR = 1 - 0.10814.t + 0.002943.t^2$ (R^2, Chi-squared and RMSE values were 0.999116, 0.000159 and 0.011984, respectively)

The Page and Diffusion Approach models also performed well. However, the magnitude of the R^2, Chi-squared and RMSE values of the Hii *et al.* and Wang Singh models under the selected drying condition were slightly better than those of the Page and Diffusion Approach models. Figures 4, 5, and 6 illustrated the goodness of fit of the Hii *et al.* and Wang Singh models when predicting the moisture ratio of clove across elapsed drying time.

Table 2. The values of drying constants, R2, $\chi 2$ (Chi-squared), and RMSE for each model evaluated at three levels of drying air velocity.

No	Model Name	Equation	Drying Air Velocity	a	B	k	d	e	R^2	χ^2	RMSE
1	Newton	$MR = exp(-a.t)$	0.5 m/s	0.098768					0.979490	0.005233	0.070985
2	Henderson and Pabis	$MR = a.exp(-b.t)$		1.113225	0.109326				0.970921	0.003879	0.059928
3	Page	$MR = exp(-a.t^b)$		0.028093	1.511941				0.996245	0.000491	0.021315
4	Midili	$MC = a\ exp(-k.t^d) + b.t$		0.967056	-0.0338	0.054816	0.527563		0.959927	0.005079	0.065774
5	Two term model	$MR = a.exp(-b.t) + k.exp(-d.t)$		0.556613	0.109326	0.556613	0.109326		0.970921	0.004216	0.059928
6	Diffusion approach	$MR = a.exp(-b.t) + (1-a).exp(-b.k.t)$		-13.7093	0.206247	0.935993			0.993536	0.000894	0.028184
7	Hii *et al.*	$MR = a.exp(-b.t^k) + d.exp(-e.t^k)$		0.478794	0.019867	1.632046	0.478794	0.019867	0.997275	0.000381	0.017609
8	Wang & Singh	$MR = 1 + a.t + b.t^2$		-0.07063	0.001202				0.996816	0.000496	0.021420
							Max R^2, Min χ^2, Min RMSE		**0.9973**	**0.0004**	**0.0176**

No	Model Name	Equation	Drying Air Velocity	a	B	k	d	e	R^2	χ^2	RMSE
1	Newton	$MR = exp(-a.t)$	1.0 m/s	0.118347					0.986563	0.002855	0.052351
2	Henderson and Pabis	$MR = a.exp(-b.t)$		1.074951	0.126706				0.981682	0.002325	0.046247
3	Page	$MR = exp(-a.t^b)$		0.053194	1.346352				0.996020	0.000481	0.021034
4	Midili	$MC = a\ exp(-k.t^d) + b.t$		0.945369	-0.03591	0.054816	0.348915		0.949081	0.006347	0.073018
5	Two term model	$MR = a.exp(-b.t) + k.exp(-d.t)$		0.556613	0.126706	0.537475	0.126707		0.981682	0.002546	0.046247
6	Diffusion approach	$MR = a.exp(-b.t) + (1-a).exp(-b.k.t)$		-14.9247	0.223331	0.950815			0.995386	0.000586	0.022713
7	Hii *et al.*	$MR = a.exp(-b.t^k) + d.exp(-e.t^k)$		0.476765	0.03898	1.457686	0.476765	0.019867	0.997166	0.000370	0.017198
8	Wang & Singh	$MR = 1 + a.t + b.t^2$		-0.08569	0.001846				0.999229	0.000082	0.008666
							Max R^2, Min χ^2, Min RMSE		**0.9992**	**0.0001**	**0.0087**

No	Model Name	Equation	Drying Air Velocity	a	B	k	d	e	R^2	χ^2	RMSE
1	Newton	$MR = exp(-a.t)$	1.5 m/s	0.15104					0.988709	0.002029	0.043962
2	Henderson and Pabis	$MR = a.exp(-b.t)$		1.049003	0.157992				0.985607	0.001852	0.040931
3	Page	$MR = exp(-a.t^b)$		0.088983	1.252732				0.994114	0.000691	0.025003
4	Midili	$MC = a\ exp(-k.t^d) + b.t$		1.05645	-0.03282	0.270682	0.313668		0.963345	0.004320	0.059140
5	Two term model	$MR = a.exp(-b.t) + k.exp(-d.t)$		0.524501	0.157992	0.524501	0.157992		0.985607	0.002070	0.040931
6	Diffusion approach	$MR = a.exp(-b.t) + (1-a).exp(-b.k.t)$		-11.868	0.264881	0.948035			0.994372	0.000710	0.024674
7	Hii *et al.*	$MR = a.exp(-b.t^k) + d.exp(-e.t^k)$		0.47696	0.068854	1.35049	0.476948	0.068852	0.995294	0.000641	0.022098
8	Wang & Singh	$MR = 1 + a.t + b.t^2$		-0.10814	0.002943				0.999116	0.000159	0.011984
							Max R^2, Min χ^2, Min RMSE		**.9991**	**.0002**	**.0120**

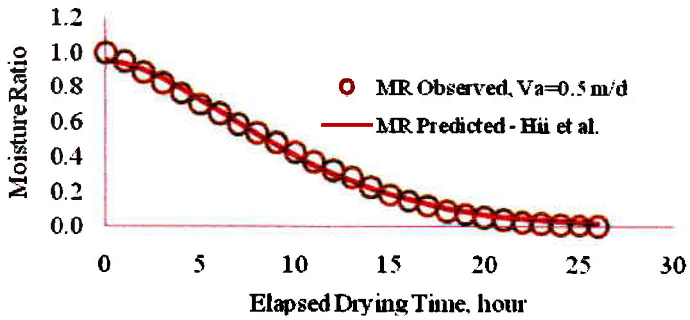

Figure 4. Observed Moisture Ratios (MR) vs. predicted values of the Hii et al. model at the drying air velocity of 0.5 m/s.

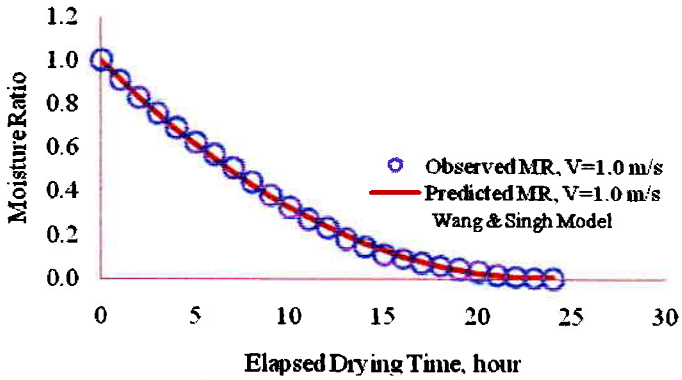

Figure 5. Observed Moisture Ratios (MR) vs. predicted values of the Wang & Singh model at the drying air velocity of 1.0 m/s.

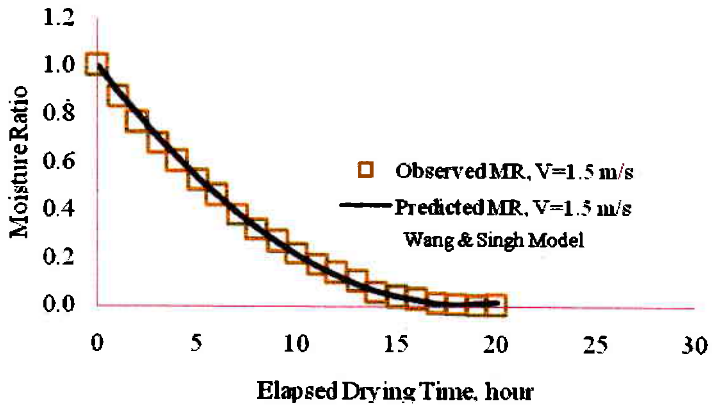

Figure 6. Observed Moisture Ratios (MR) vs. predicted values of the Wang & Singh model at the drying air velocity of 1.5 m/s.

Conclusion

This study concluded that drying air velocity indeed affect the drying rate of mature green clove. It was also found that among eight models evaluated, Hii *et al.* model is appropriate to represent the behavior of the clove drying rate at the drying air velocity of 0.5 m/s under a constant drying temperature of 45 °C. On the other hand, Wang and Singh model is the best choice at the drying air velocities of 1.0 and 1.5 m/s.

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